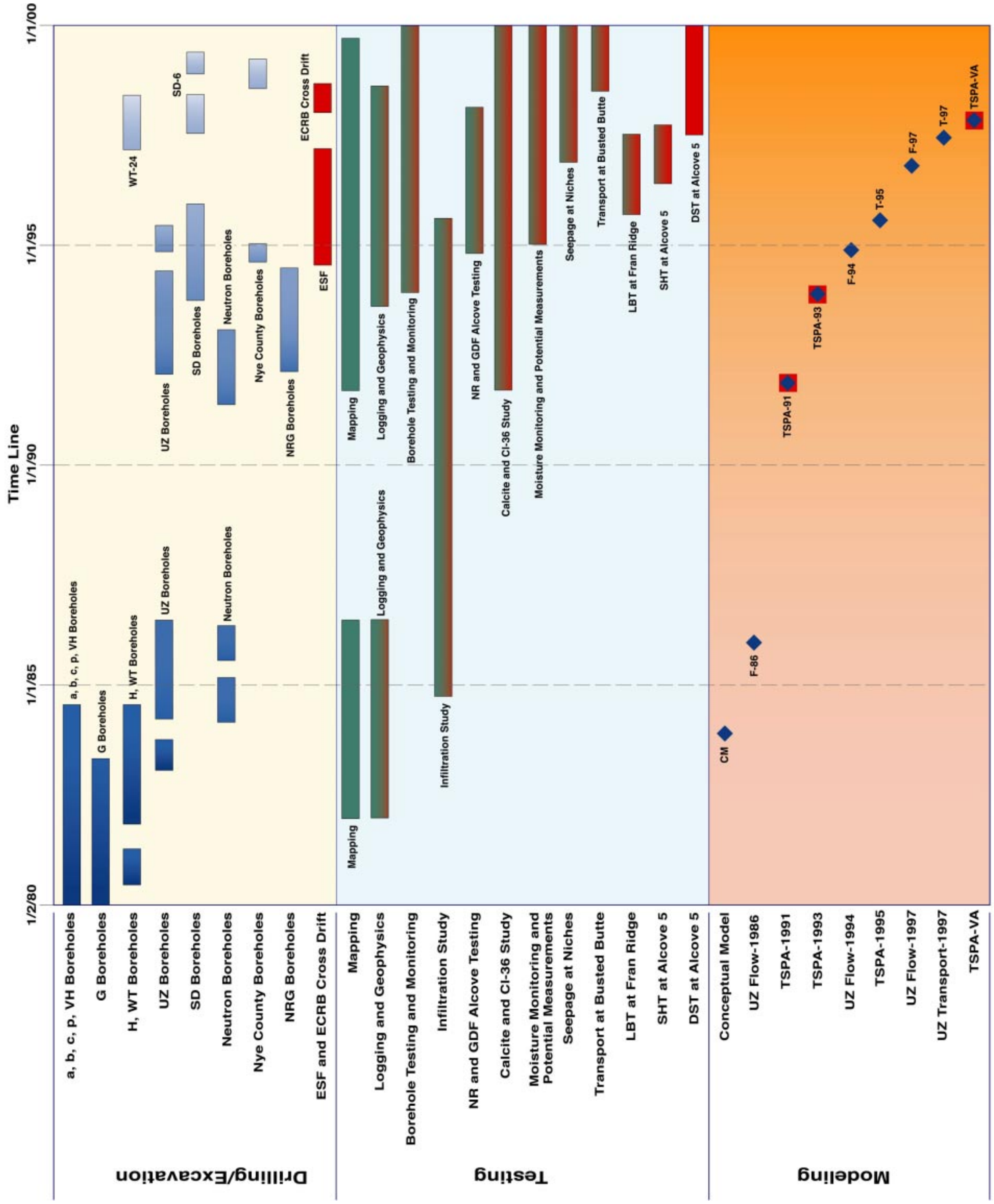
Chapter 2 Figures



Time Line
1/2/80
1/1/85
1/1/90
1/1/95
1/1/00
Drilling/Excavation
Testing
Modeling
a, b, c, p, VH Boreholes
G Boreholes
H, WT Boreholes
UZ Boreholes
SD Boreholes
Neutron Boreholes
Nye County Boreholes
NRG Boreholes
ESF and ECRB Cross Drift
Mapping
Logging and Geophysics
Borehole Testing and Monitoring
Infiltration Study
NR and GDF Alcove Testing
Calcite and Cl-36 Study
Moisture Monitoring and Potential Measurements
Seepage at Niches
Transport at Busted Butte
LBT at Fran Ridge
SHT at Alcove 5
DST at Alcove 5
Conceptual Model
UZ Flow-1986
TSPA-1991
TSPA-1993
UZ Flow-1994
TSPA-1995
UZ Flow-1997
UZ Transport-1997
TSPA-VA
WT-24
SD-6
ESF
ECRB Cross Drift
CM
F-86
TSPA-91
TSPA-93
F-94
T-95
F-97
T-97

Figure 2.1-1.

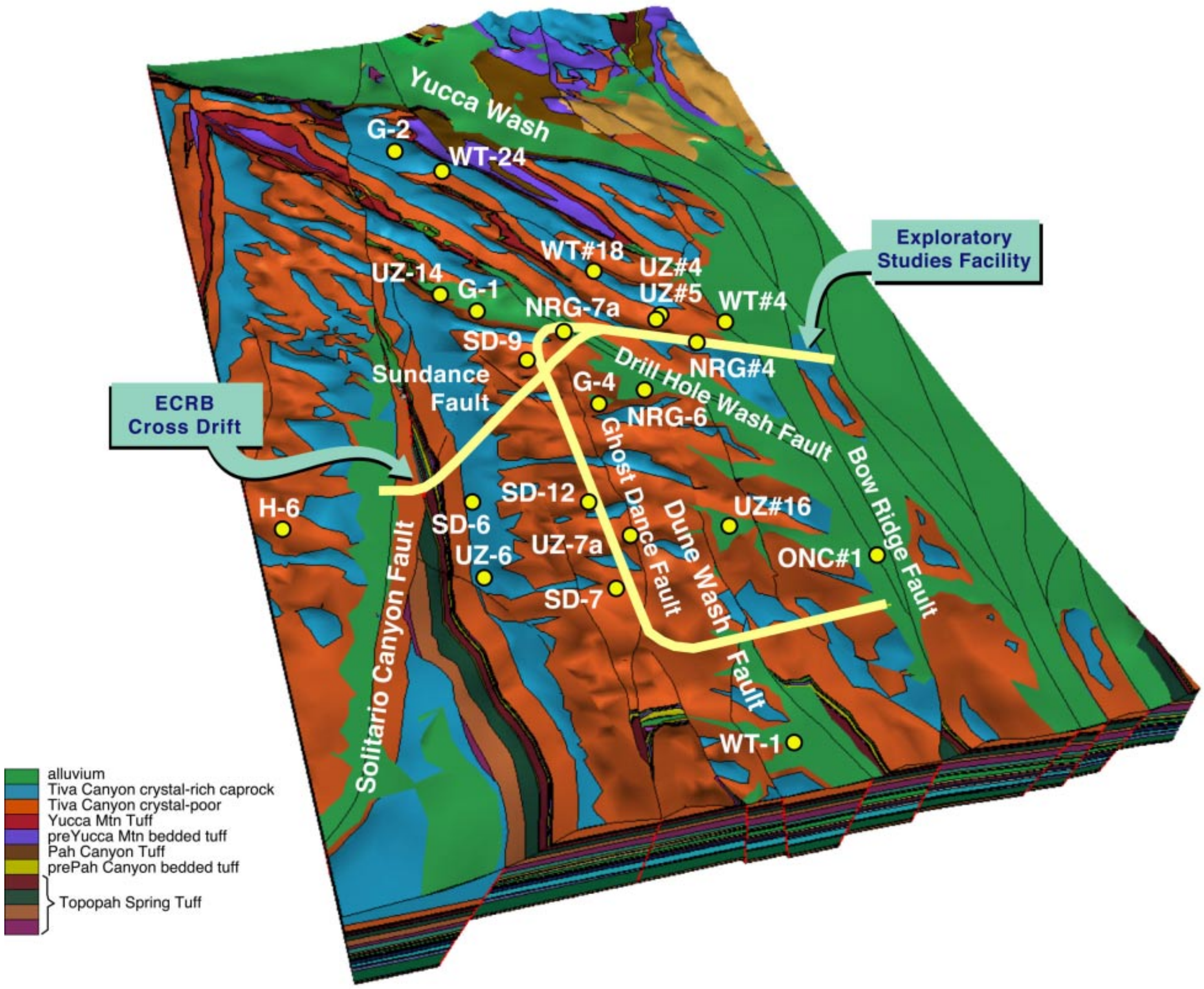

Yucca Wash
G-2
WT-24
Exploratory Studies Facility
WT#18
UZ#4
UZ-14
G-1
UZ#5
WT#4
NRG-7a
SD-9
NRG#4
Sundance Fault
G-4
Drill Hole Wash Fault
ECRB Cross Drift
NRG-6
Bow Ridge Fault
Ghost Dance Fault
H-6
SD-12
UZ#16
SD-6
Dune Wash Fault
UZ-7a
ONC#1
UZ-6
SD-7
Solitario Canyon Fault
WT-1
alluvium
Tiva Canyon crystal-rich caprock
Tiva Canyon crystal-poor
Yucca Mtn Tuff
preYucca Mtn bedded tuff
Pah Canyon Tuff
prePah Canyon bedded tuff
Topopah Spring Tuff

Figure 2.1-2.

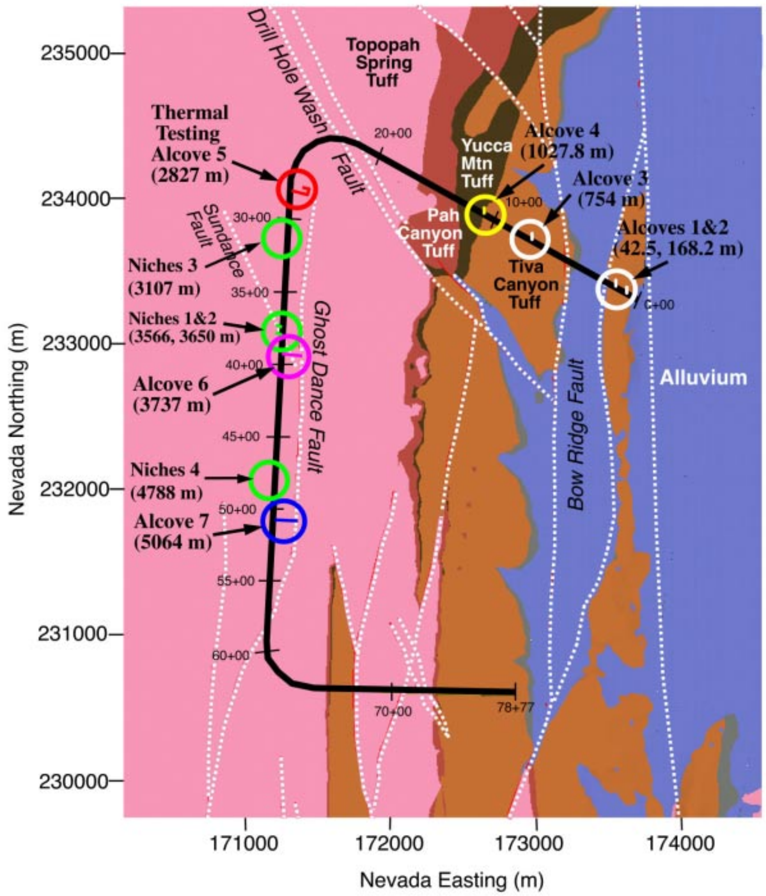
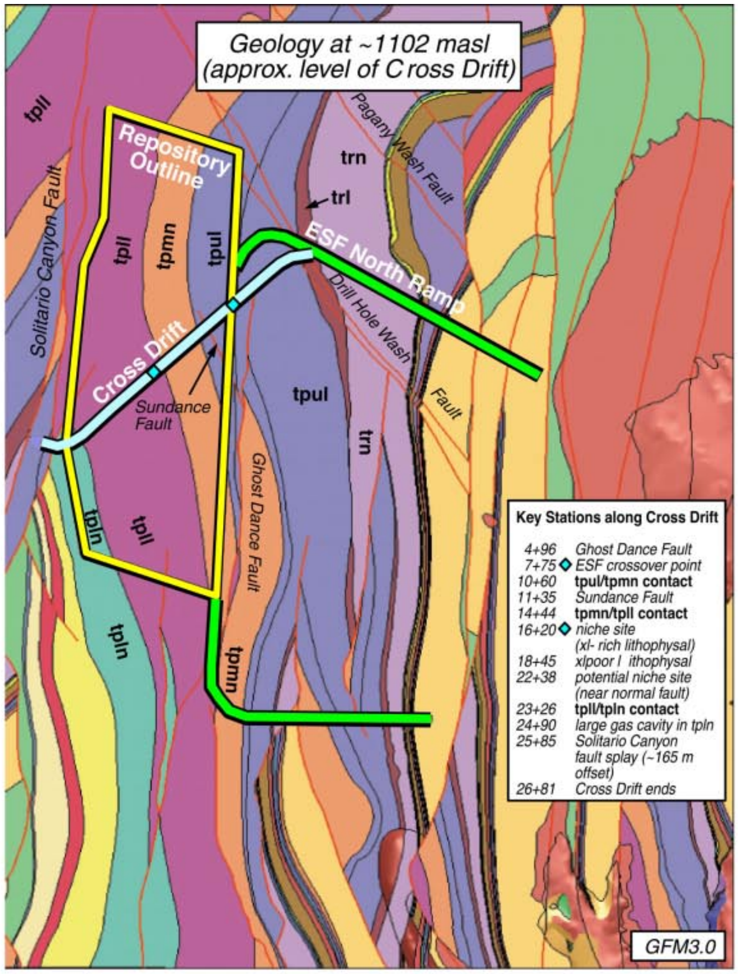

Drill Hole Wash Fault
Topopah Spring Tuff
Thermal Testing Alcove 5 (2827 m)
20+00
Yucca Mtn Tuff
Alcove 4 (1027.8 m)
Alcove 3 (754 m)
10+00
30+00
Sundance Fault
Pah Canyon Tuff
Alcoves 1&2 (42.5, 168.2 m)
Niches 3 (3107 m)
35+00
Tiva Canyon Tuff
0+00
Niches 1&2 (3566, 3650 m)
Ghost Dance Fault
40+00
Alcove 6 (3737 m)
Alluvium
Bow Ridge Fault
45+00
Niches 4 (4788 m)
50+00
Alcove 7 (5064 m)
55+00
60+00
70+00
78+77
235000
234000
233000
232000
231000
230000
Nevada Northing (m)
171000
172000
173000
174000
Nevada Easting (m)

Figure 2.1-3.

(a)



(b)

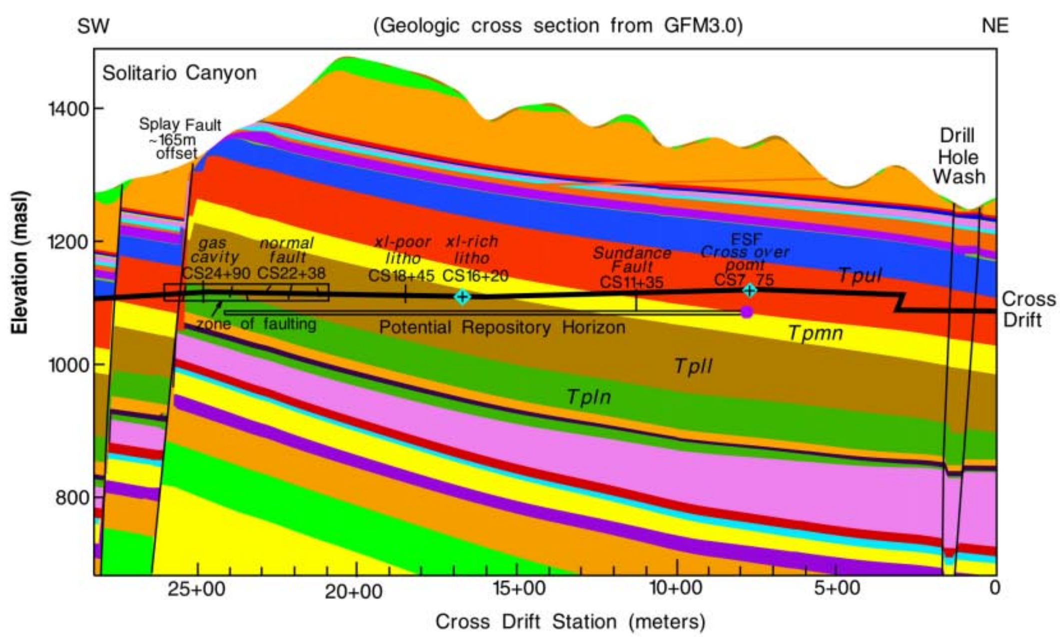


Figure 2.1-4.

Geologic Mapping and Geophysical Studies on Surface and in ESF

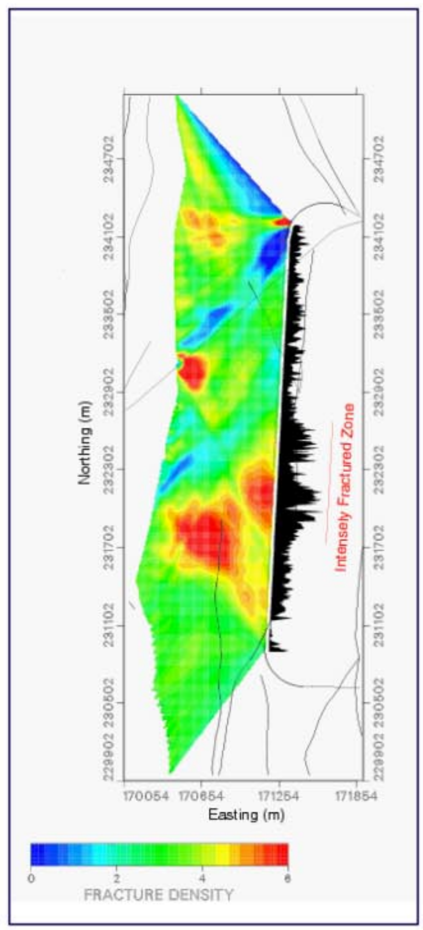
(a) Drilling of Borehole SD-6 on the Crest of Yucca Mountain

(b) Pavement Cleared for Ghost Dance Fault Mapping

Objectives:
- Determine lithology and structural features of tuff units.
- Evaluate distribution of fractures and faults.

Approaches:
- Map features on bedrock, in trenches, and along ESF drifts.
- Conduct geophysical logging along boreholes.
- Deploy geophysical tomographic imaging techniques on the surface and in underground drifts.

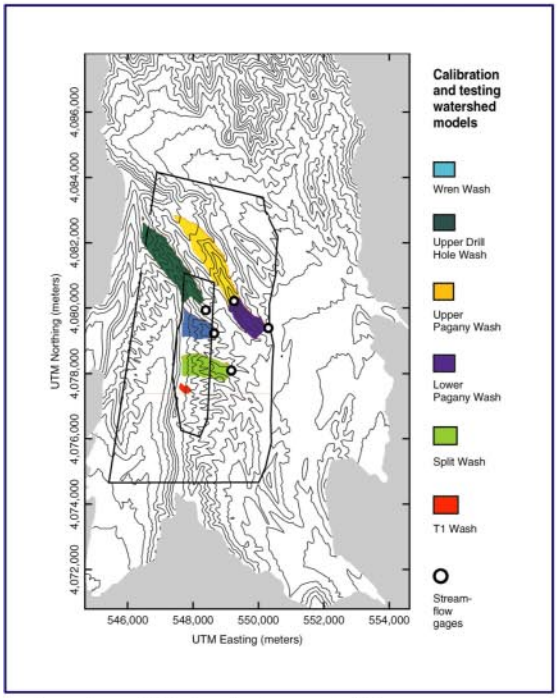
Results:
- Refined geological maps of bedrock, washes and faults.
- Improved geological framework of tuff layers and fault offsets.
- Detailed line surveys and full peripheral maps along drifts.
- Interpreted fracture density distributions between surface and underground drifts.



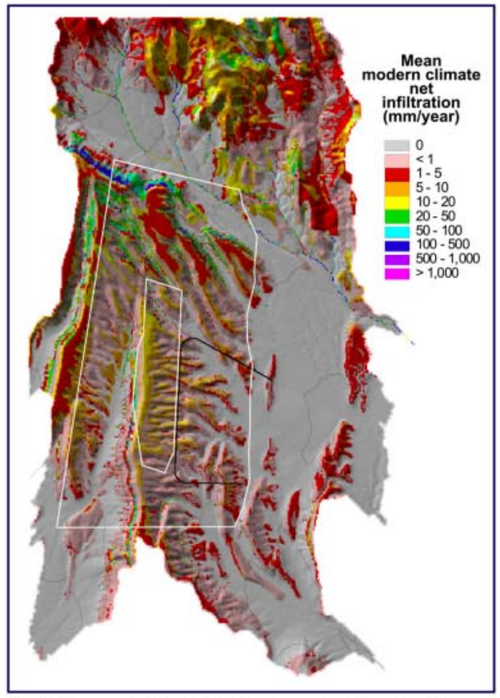
(c) Fracture Density Distributions by Detailed Line Survey and Seismic Tomograph

Figure 2.2-1.

Infiltration Study on the Bedrock and in Washes



(a) Location of Washes Instrumented for Watershed Study



(b) Estimated Net Infiltration (mm/yr) for the Mean Modern Climate Scenario

Objectives:

- Provide upper boundary conditions for UZ Flow and Transport Model.
- Evaluate infiltration processes and mechanisms for determining net infiltration under current dry and future wet conditions.

(c) Neutron Logging at Pagany Wash

Approaches:

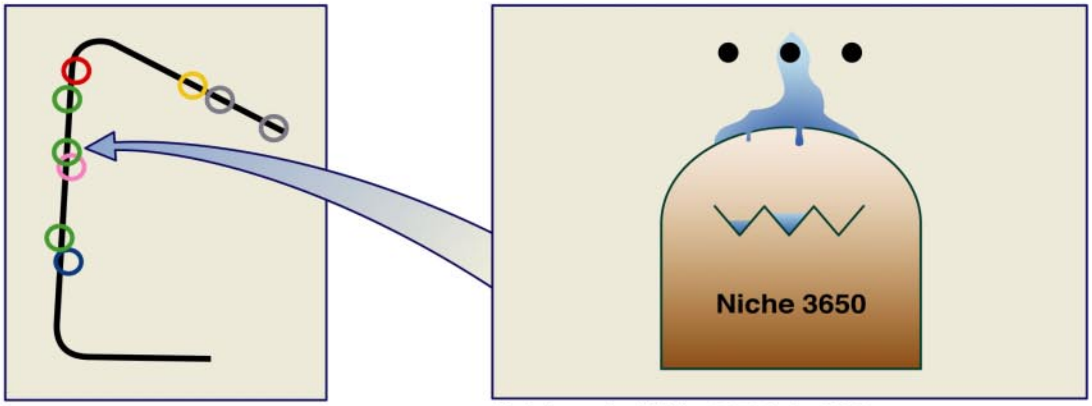
- Conduct periodic neutron logging in network of shallow boreholes.
- Record climate changes and evaluate evapotranspiration potentials.
- Instrument washes to evaluate run-on and run-off processes.

Results:

- Improved infiltration maps for current, monsoon, and glacial-transition climates.
- Quantification of relationships between precipitation and net infiltration.
- Quantification of downward flux and lateral run-on and run-off processes.

Figure 2.2-2.

Drift Seepage Test at Niche 3650



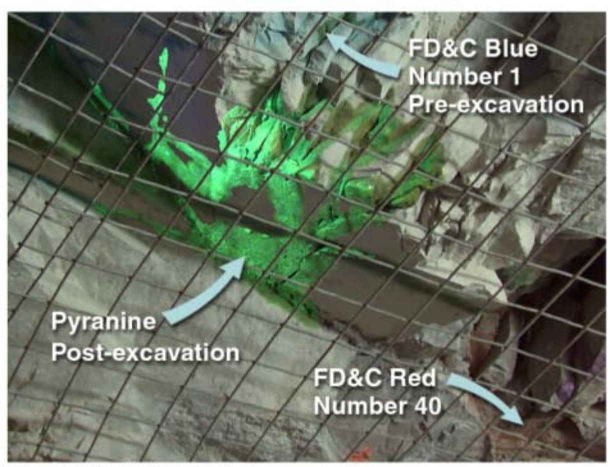
(a) Schematic of Niche 3650 in the ESF

Objectives:
- Quantify seepage threshold below which no seepage occurs.
- Evaluate capillary barrier mechanism and measure drift-scale parameters.

Approaches:
- Use air injection tests to characterize the niche site with resolution of 0.3-m scale (one tenth of drift dimensions).
- Use pulse releases to represent episodic percolation events.
- Determine seepage thresholds by sequences of liquid releases with reducing rates.
- Derive in situ fracture characteristic curves with wetting front arrival analyses.

Results:
- Measured seepage threshold ranges from <u>200 mm/yr</u> to 136,000 mm/yr at localized release intervals.
- Six out of sixteen tested intervals did not seep.
- Observe both flow along high-angle fractures and flow through fracture network.
- Derive fracture capillary parameters and characteristic curves, with equivalent fracture porosity as high as 2.4%.

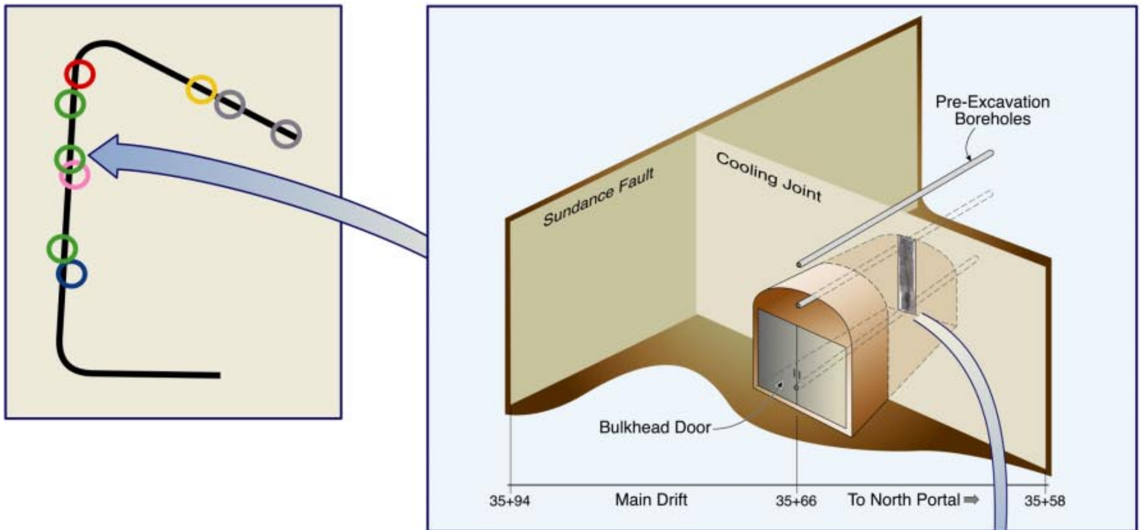
(b) Water Collection During a Drift Seepage Test



(c) Flow Paths Indicated by Dye Tracers

Figure 2.2-3.

In Situ Wet Feature Observed at Niche 3566



(a) Schematic of Sealed Niche 3566 in the ESF

Objectives:

- Characterize the hydrologic setting of a site with bomb-pulse ^{36}Cl signals, the Sundance fault and its first cooling joint.
- Quantify seepage processes.

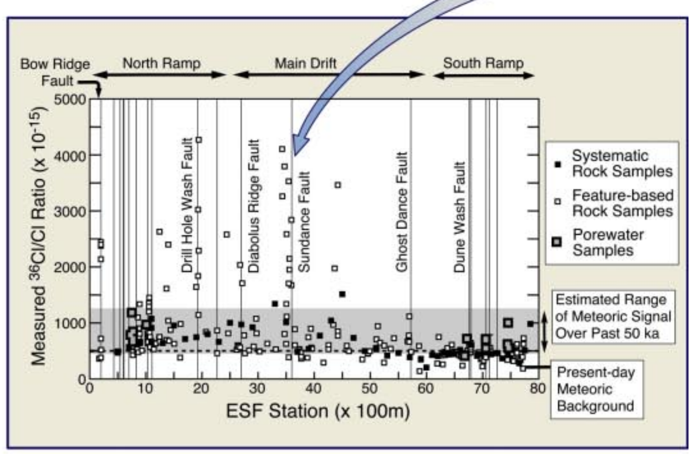
Approaches:

- Mine the niche without spreading water to the ceiling during excavation.
- Close the bulkhead to prevent moisture removal by ventilation.
- Monitor the rock and drift over long time periods.

Results:

- One damp feature observed after dry excavation at end of the niche. It dried up before bulkhead installation and did not rewet after long-term monitoring over two years.

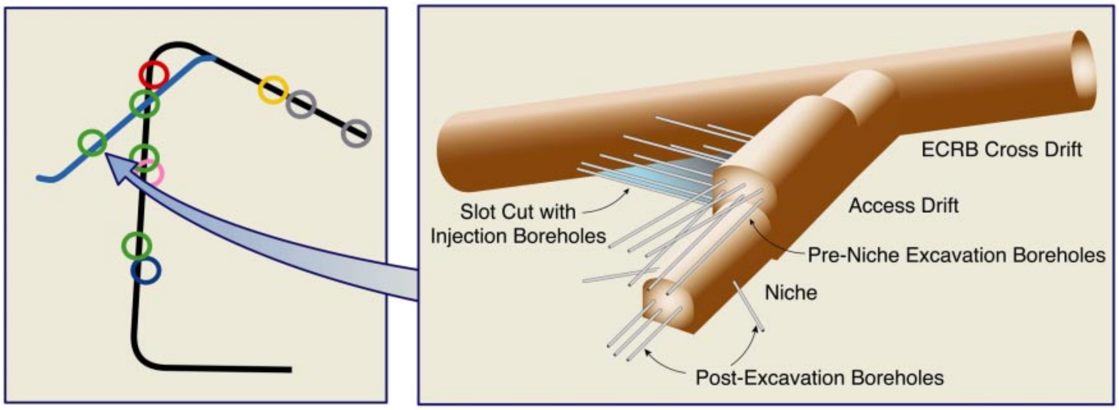
(b) Photograph of a Damp Feature in the Brecciated Zone at the Back of Niche 3566



(c) Distribution of $^{36}Cl/Cl$ in the ESF

Figure 2.2-4.

Drift Seepage Test at ECRB Cross Drift Niche 1620



(a) Schematic of Niche 3107

Objectives:

- Quantify seepage into drift in the lower lithophysal unit at a cavity-rich zone.
- Characterize the pneumatic and liquid flows in the presence of lithophysal cavities and porous tuff.
- Determine the differences between lower lithophysal unit and middle non-lithophysal unit of the potential repository rock.
- Quantify fracture-matrix interaction at lower lithophysal unit.

Approaches:

- Observe flow paths during dry excavation, use air-injection tests to characterize liquid release intervals, and conduct drift seepage tests with liquid releases at different rates.
- Adopt, improve, and extend the methodologies used in tests conducted in the middle non-lithophysal niches and test beds.

Results:

- Pre-excavation air-injection test results suggest that lower lithophysal unit has higher permeability than middle non-lithophysal unit.
- Access drift has been excavated with an Alpine Miner.
- Seepage tests are prepared to be conducted after niche excavations.

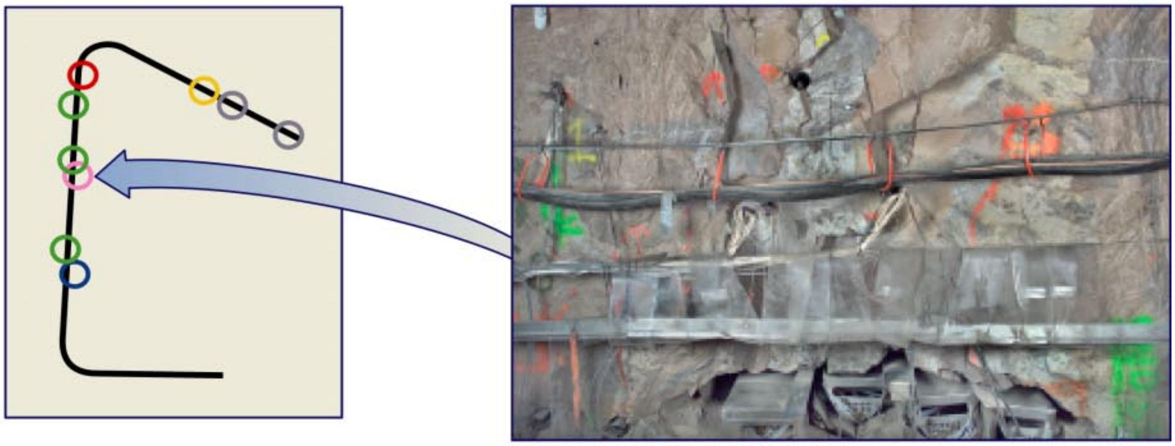
(b) Alpine Miner Excavating the Access Drift

(c) Example of a Cavity in the Lower Lithophysal Tuff Unit

(d) Scanner Image along Borehole AK-1 at Niche1620

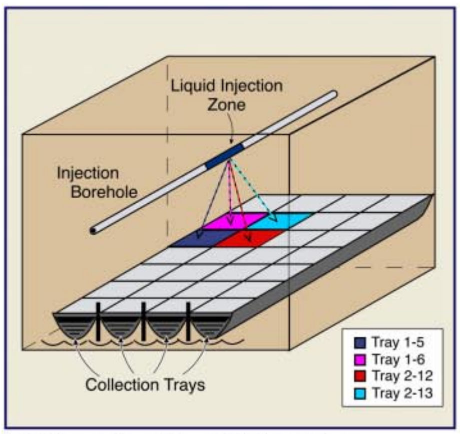
Figure 2.2-5.

Fracture-Matrix Interaction Test at Alcove 6



(a) Photograph of Alcove 6 Test Bed

(b) Close-up of Trays on the Slot



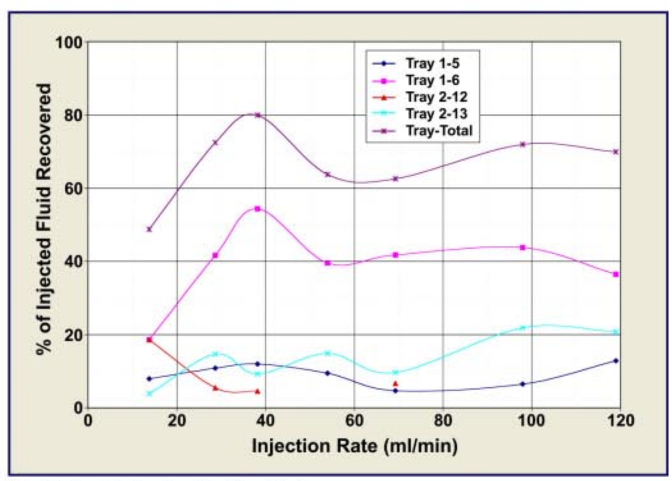
(c) Schematic of Liquid Release Test

Objectives:

- Quantify fracture-matrix interaction and the fraction of fracture flow.

Approaches:

- Use a slot below boreholes to capture fracture flows.
- Estimate the fracture/matrix flow partitioning by mass balance.
- Use borehole sensors to detect wetting front arrivals.



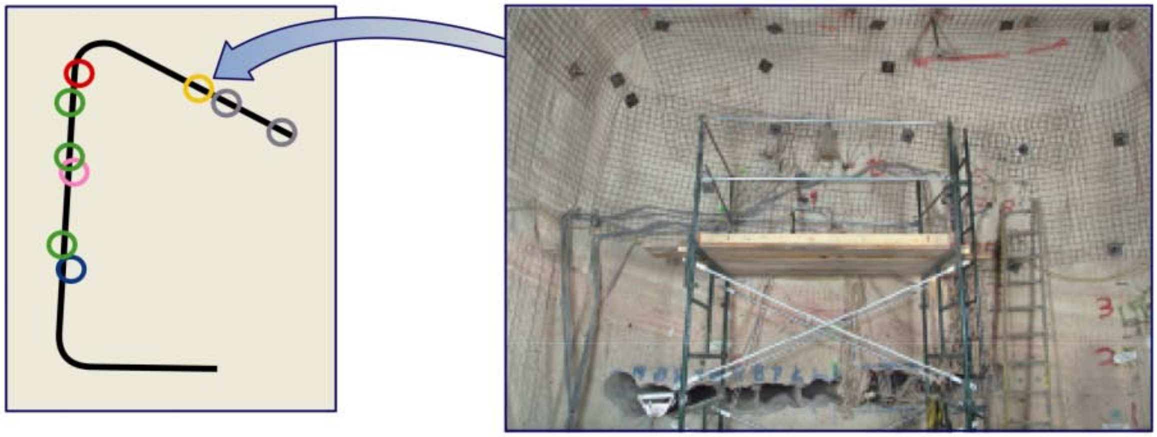
(d) Water Collected in the Slot

Results:

- A maximum of 80% of injected water was recovered for high-rate injection tests (i.e. 80% fracture flow).
- Out flows occurred in step increments which could be related to water stored in fracture flow paths.

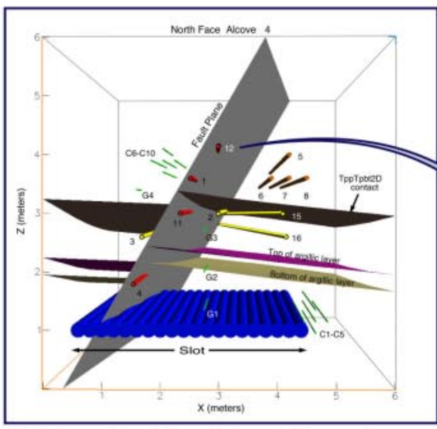
Figure 2.2-6.

Fault Flow Damping Test at Alcove 4

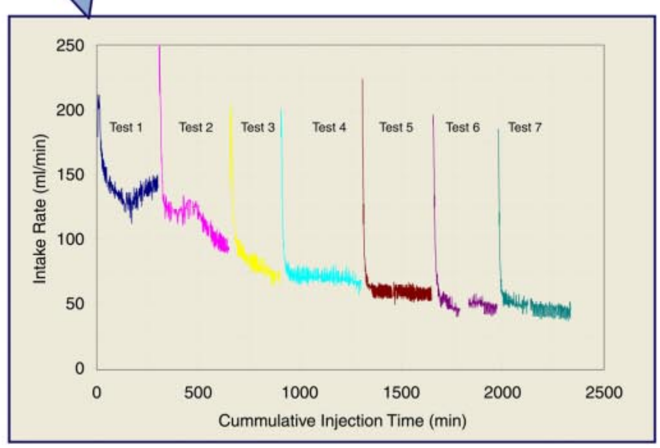


(a) Photograph of Alcove 4 Test Bed

(b) Close-up of Tray on the Left-Hand Side of the Slot



(c) Schematic of Boreholes at Alcove 4



(d) Water Intake Rate at a PTn Fault

Objectives:

- Evaluate flow mechanism in the Paintbrush nonwelded tuff unit.
- Quantify the damping and lateral diversion processes along a fault and along bedded tuff interfaces.

Approaches:

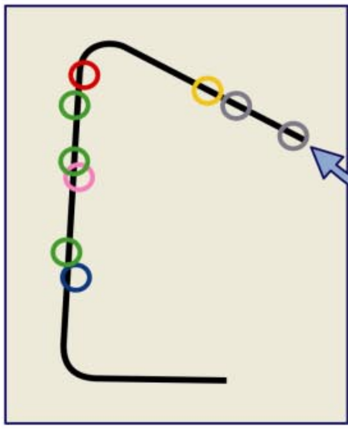
- Select a test bed containing bedded tuff layers (including an argillic layer), a fault, and a fracture.
- Release water under constant-head conditions to determine the intake rates.
- Monitor wetting front arrivals and measure potential changes in boreholes.

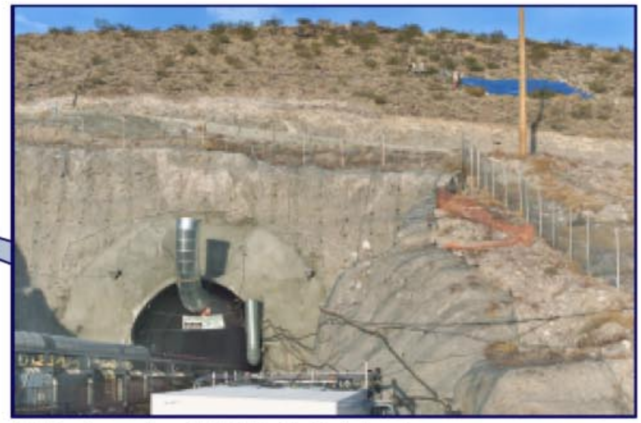
Results:

- Water intake rates in the fault decreases as more water was introduced into the release zone.
- Clay Swelling is one mechanism proposed to interpret the field data.
- In sequence of tests, wetting front travel faster with more water released into the fault.

Figure 2.2-7.

El Niño Infiltration Test at Alcove 1





(a) Photography of ESF North Portal and Infiltration Plot (Blue Cover)

Objectives:

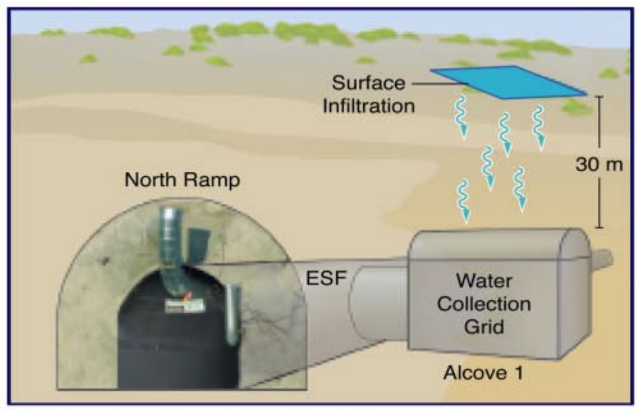
- Quantity large-scale infiltration and seepage processes in the bedrock.
- Evaluate matrix diffusion mechanism in long-term flow and transport tests.

Approaches:

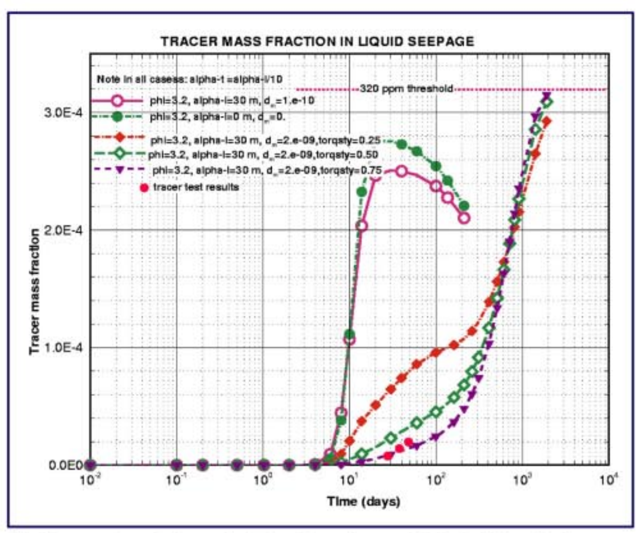
- Water applied on the surface 30 m directly above the alcove.
- Tests conducted in two phases: March - August 1998 and May 1999 - present, with Phase 1 focusing on flow and Phase 2 focusing on tracer transport.

Results:

- Over 100,000 liters infiltrated in Phase 1, with observed seepage rates of up to 300 liter/day.
- Breaththrough times were on the order of 2 days, with the exception of the first arrival in 58 days.
- High concentrations of LiBr were used in Phase 2 tracer test.
- Tracer recovery data were used to compare with model predictions and to evaluate the importance of matrix diffusion.



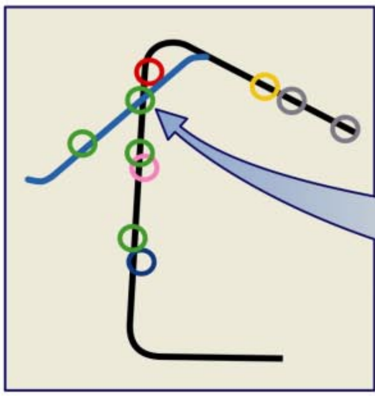
(b) Schematic of Alcove 1 Infiltration Test

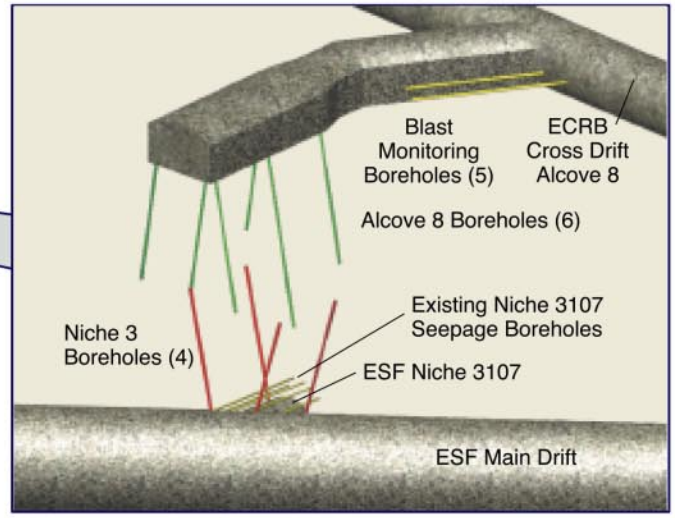


(c) Tracer Breakthoughs Test Results and Model Predictions with Matrix Diffuson

Figure 2.2-8.

Alcove 8-Niche 3107 Cross-Drift Test





(a) Schematic of the Cross Drift Test Bed

Objectives:
- Quantify large-scale infiltration and seepage processes in the potential repository horizon.
- Evaluate matrix diffusion mechanism in long-term flow and transport tests across an lithophysal-nonlithophysal interface.

Approaches:
- Water releases are in Alcove 8 and seepage collections are in Niche 3107.
- Niche 3107 is instrumented with seepage collectors and wetting front sensors.
- Geophysical tomographs are conducted in vertically slanted boreholes.

Status:
- Drill-and-blast phase of Alcove 8 excavation was completed in 1999.
- Tests are prepared to be conducted after alcove excavation.

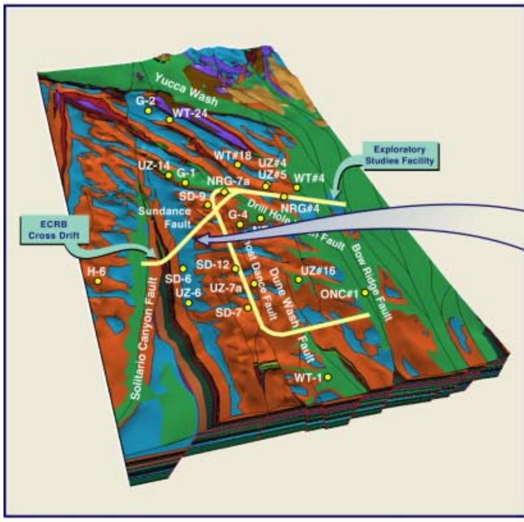
Supporting Results:
- Seepage tests at Niche 3107 behind bulkhead demonstrate the existence of seepage threshold under high humidity conditions.
- During ECRB Cross Drift construction, no water was observed to seep into the ESF Main Drift 20 m below.

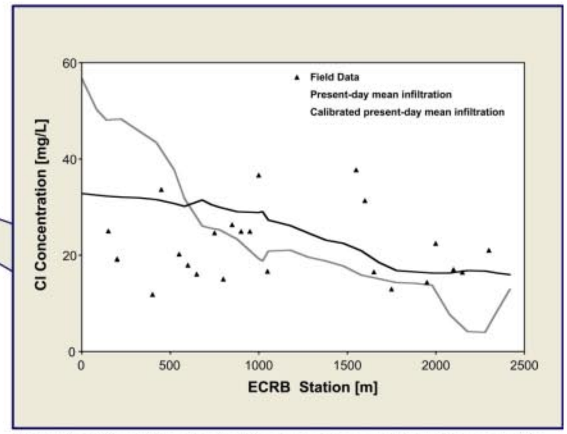
(b) Photograph of Partial Excavated Alcove 8 in ECRB Cross Drift

(c) Photograph of Water Collection Trays on the Ceiling of the ESF Main Drift

Figure 2.2-9.

Geochemical Measurements on Borehole and ESF Samples





(a) Total Chloride Contents Along the ECRB Cross Drift

Objectives:

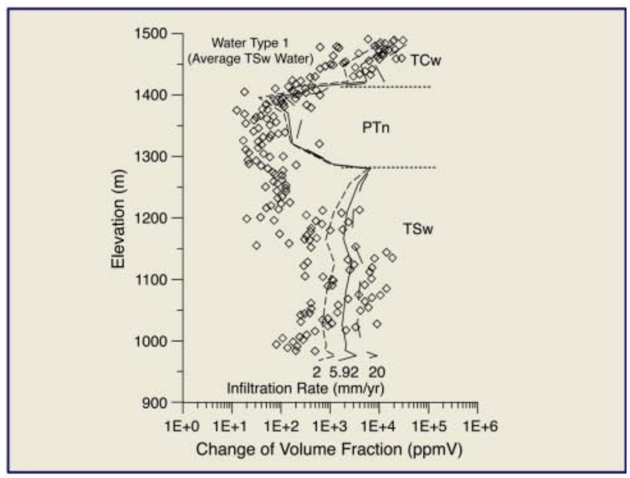
- Provide data to define geochemical evolution of water in the UZ.
- Provide data to estimate percolation flux at depth.

Approaches:

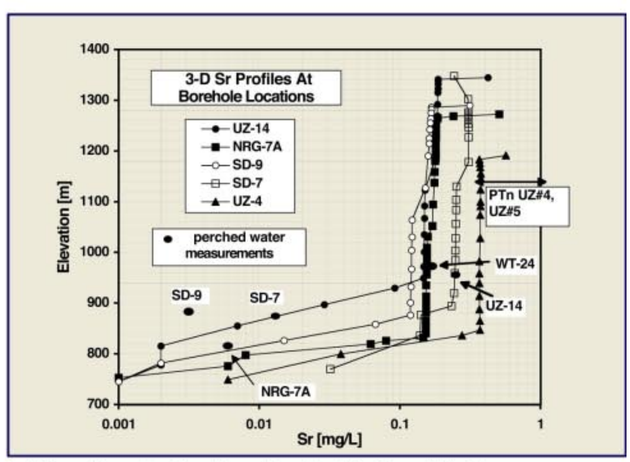
- Collect gas and perched water samples by pumping.
- Extract pore water by compression, ultrcentrifugation, or vacuum distillation.
- Determine major ion concentrations by chemical analyses.

Results:

- Total dissolved solid and chloride are used to estimate infiltration rates and percolation fluxes.
- Pore waters are related to soil-zone processes: evapotranspiration, dissolution and precipation of pedogenic calcite and amorphous silica.
- Deep pore waters are used to evaluate restricted water-rock interactions and significant lateral movement within Calico Hills unit.



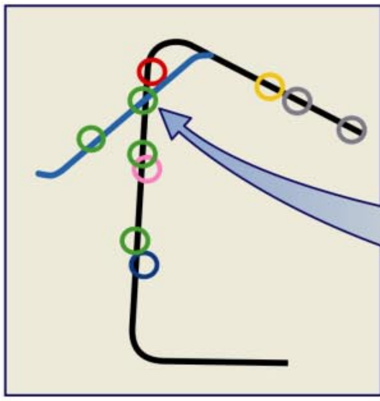
(b) Calcite Distributions Used for Infiltration and Percolation Evaluations



(c) Strontium Profiles Used for Zeolite Quantification

Figure 2.2-10.

Isotopic Measurements on Fracture Minerals and Perched Waters

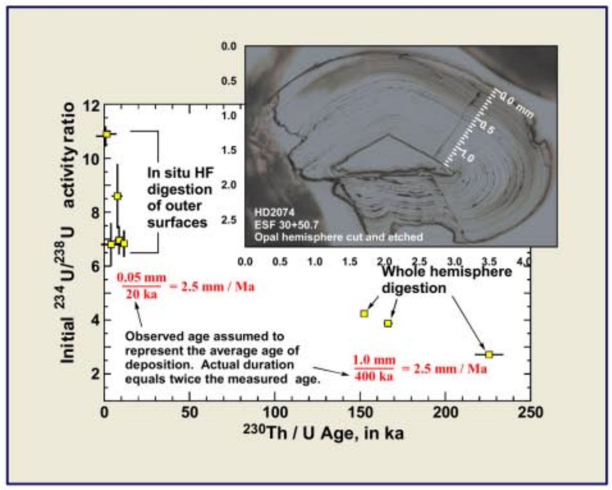


(a) Photograph of a Fracture with Calcite Infill

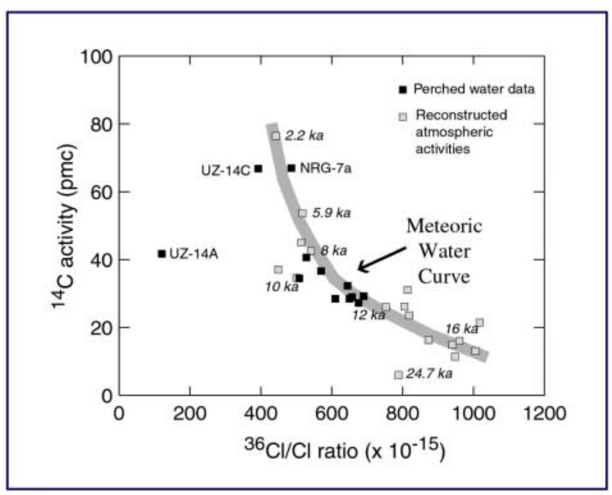
Objectives:
- Provide isotopic data to define age evolution of water in the UZ.
- Provide data to delineate flow paths over geological time scales.

Approaches:
- Leach salts from UZ cores or cutting for ^{36}Cl and Sr isotopic analyses.
- Extract water for tritium, hydrogen and oxygen stable isotopes, and carbon isotopic analyses.
- Digest mineral samples for analyses of Sr isotope ratios and of U series nuclides.

Results:
- Bomb-pulse ^{36}Cl/Cl signals are present in the vicinity of some fault zones in the ESF.
- Detectable levels of tritium are present in ~6% of pore waters sampled.
- Bomb-pulse ^{36}Cl/Cl and tritium signals are not present in perched waters.
- Age of perched waters, mixing between fast and slow flows, climate of recharge are estimated by carbon and stable isotope analyses.
- ^{234}U/^{238}U activity ratios indicate recharge through fractures and minimal exchange between pore water and fracture water.



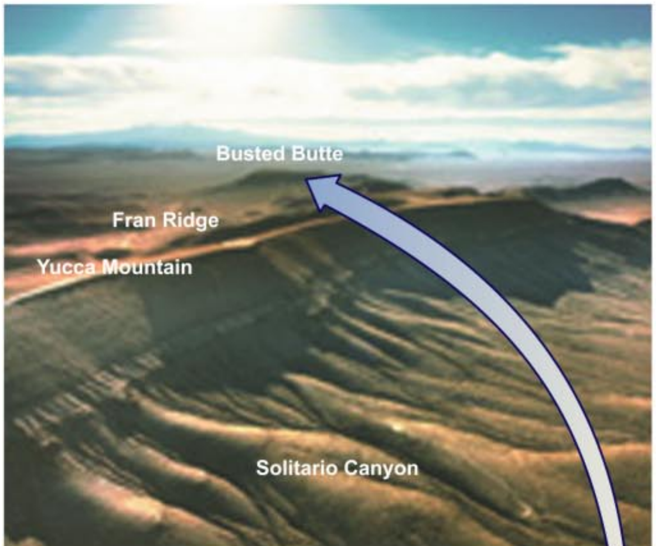
(b) Low and/or Infrequent Fracture Flow Based on Opal and Calcite Deposit Analyses

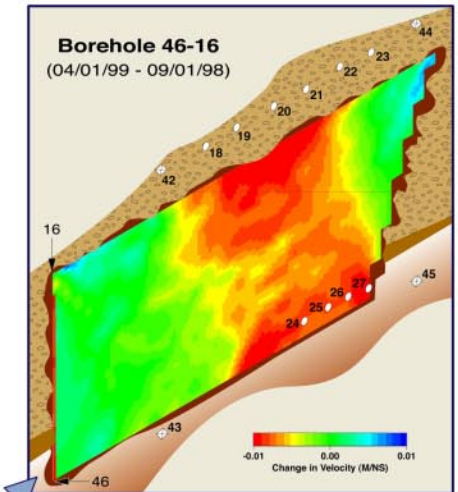


(c) Perched Water Ages Determined by ^{14}C and ^{36}Cl/Cl Data

Figure 2.2-11.

UZ Transport Test at Busted Butte





(a) Ground Penetrating Radar Tomograph of Injected Plume (Phase 2)

Objectives:

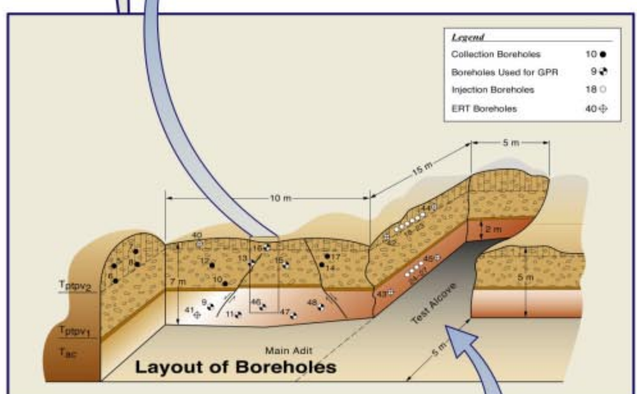
- Quantify UZ transport processes in Calico Hills nonwelded unit.
- Measure retardation coefficients in the field to compare with laboratory measured values.

Approaches:

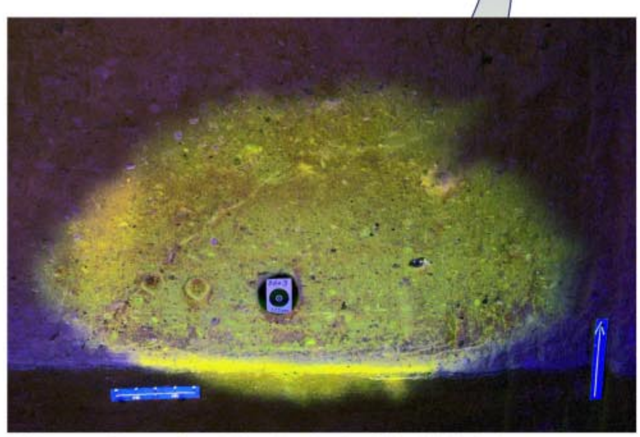
- A test bed was excavated 70 m below the surface in mainly vitric CHn underlying the vitrophyre.
- A mixture of conservative and sorbing tracers is used in tracer injection tests.
- Absorbent pads are used to sample periodically the tracer distributions below injections.
- Ground-penetrating radar tomography, together with electrical resistivity tomography and neutron logging, are used to track plume migrations.

Results:

- Phase 1A was conducted with single point injections from April 1998 to mineback in 1999. Capillary driven flow mechanism is confirmed.
- Phase 2 tests with areal injections are on-going with breakthroughs and plume migrations monitored.



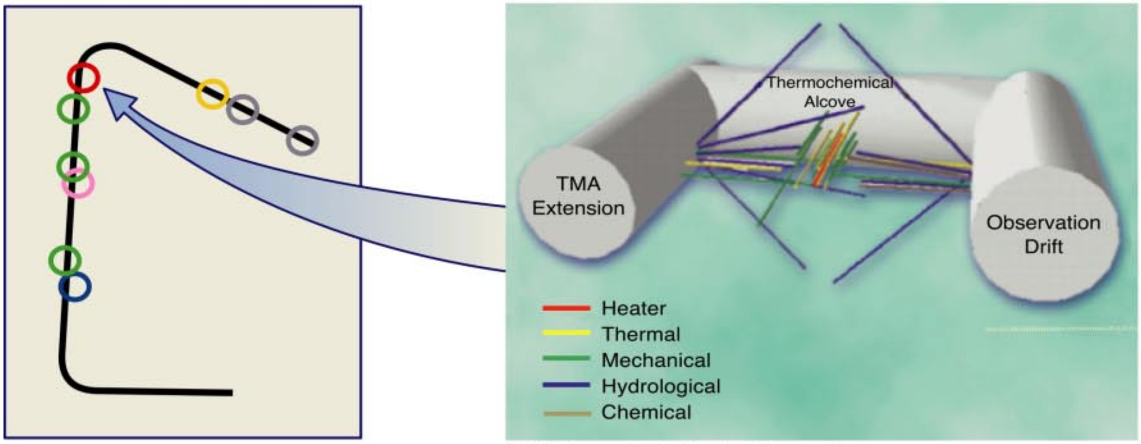
(b) Schematic of Busted Butte Test Area



(c) Tracer Plume from Injection in the Side Wall of the Main Adit, Opposite to the Test Alcove (Phase 1A)

Figure 2.2-12.

Single Heater Test at Alcove 5



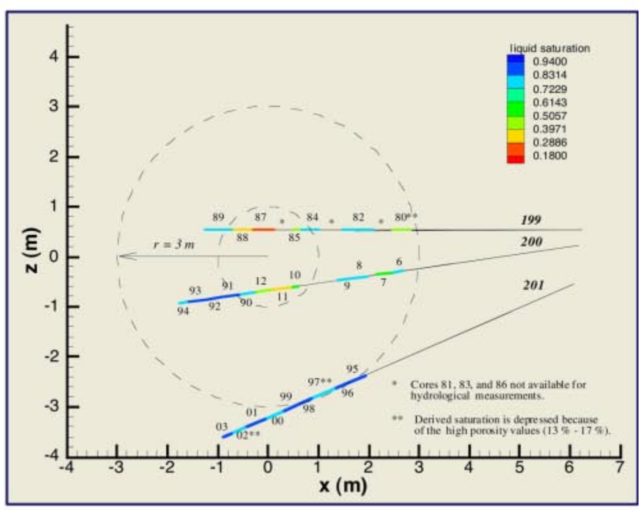
(a) Schematic of Single Heater Test

Objectives:
- Evaluate THMC coupled processes around a line heater source in fractured tuff.
- Develop testing methodologies and modeling approaches for high temperature conditions.

Approaches:
- Heating with a 5-m long 4-kW heater lasted 9 months in 1996 and 1997.
- Borehole sensing and cross-hole testing were used before, during, and after heating period.

Results:
- Extent of dry-out of about 1 m around the heater hole was measured with geophysical techniques (ERT, GRP and neutron).
- Condensate zone below the heater was measured to be larger than above the heater horizon.
- Chemical composition of water collected during heating in packed borehole intervals was analyzed.
- Characterization data by air-injection tests and mechanical displacement measurements located high-k flow paths.

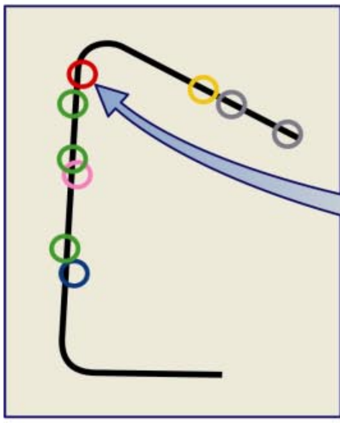
(b) Photograph of Single Heater Test Block Insulated



(c) Distributed Liquid Saturation in Cores After Cooling Phase

Figure 2.2-13.

Drift Scale Test at Alcove 5



Objectives:

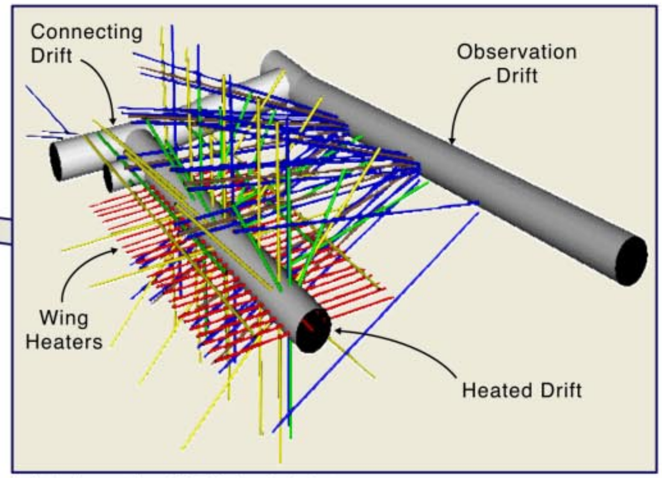
- Evaluate THCM coupled processes in emplacement drift scale with full-scale heaters.
- Evaluate multi-drift heating effects with wing heaters to simulate multi-drift test conditions in fractured tuff.

Approaches:

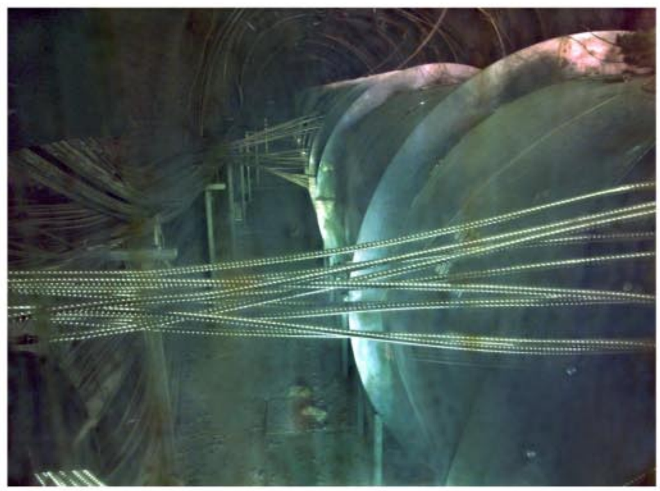
- Install extensive borehole sensor arrays for monitoring of heating responses.
- Perform periodic geophysical imaging, pneumatic testing, and fluid sampling to measure the thermally induced coupled effects.

Results:

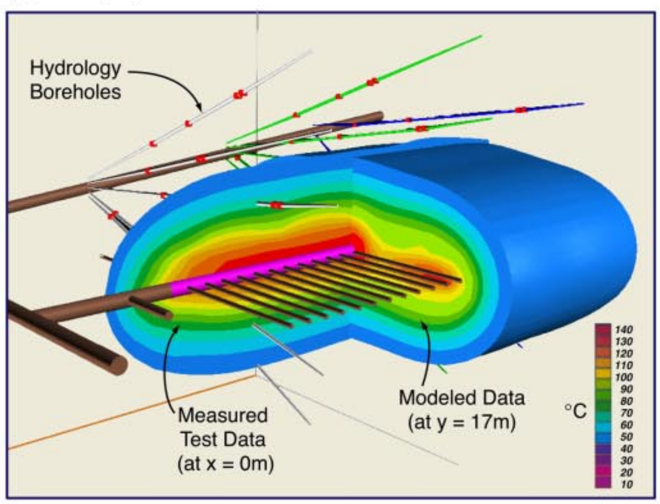
- Drift wall temperature reached ~190°C after 2 years of heating (since December 1997 at 187 kW).
- Condensate accumulated mainly below the wing heaters at early times.
- Wetting and drying zones were identified by periodic air-injection tests and geophysical methods.
- Gas phase CO_2 concentration increased strongly in large region around the heaters.
- Interactions of calcite and silicate minerals were indicated by chemical analyses of water collected.



(a) Schematic of Drift Scale Test

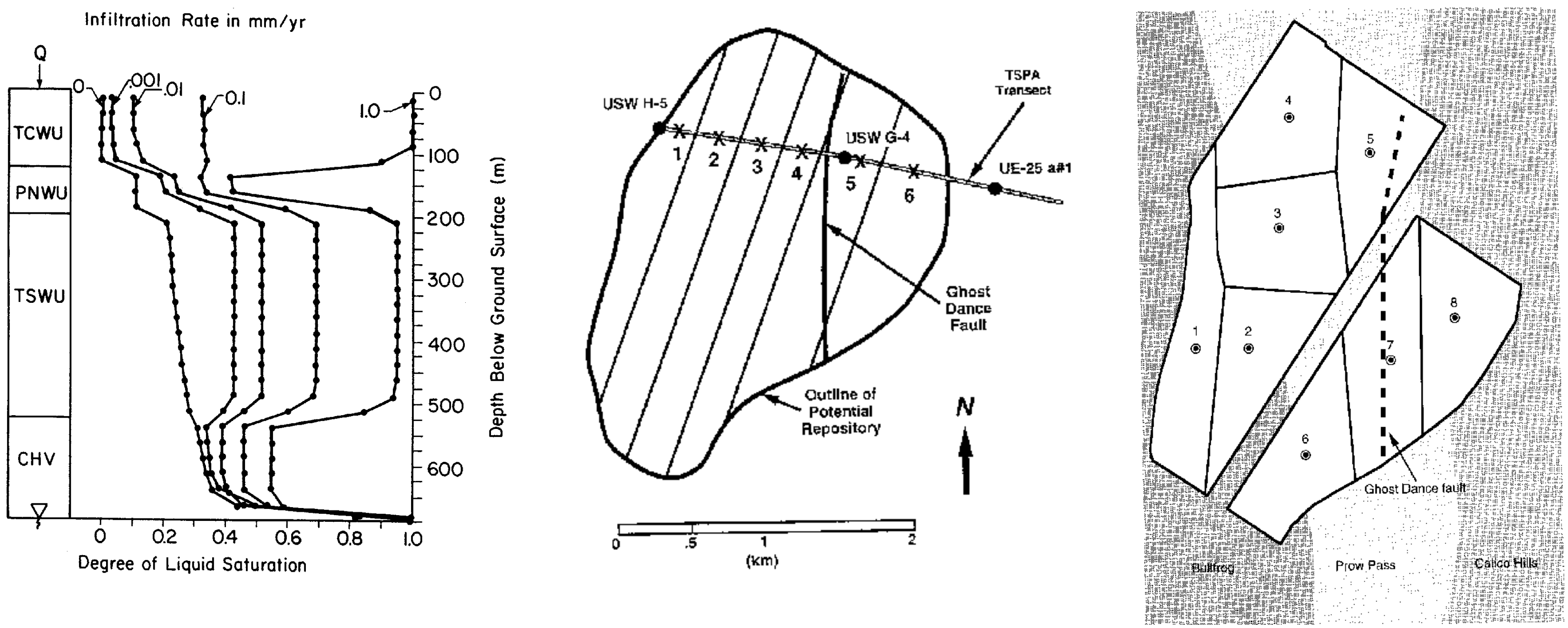


(b) Photograph of Full Scale Heaters within Heated Drift



(c) Comparison of Measured and Modeled Temperature Distributions

Figure 2.2-14.

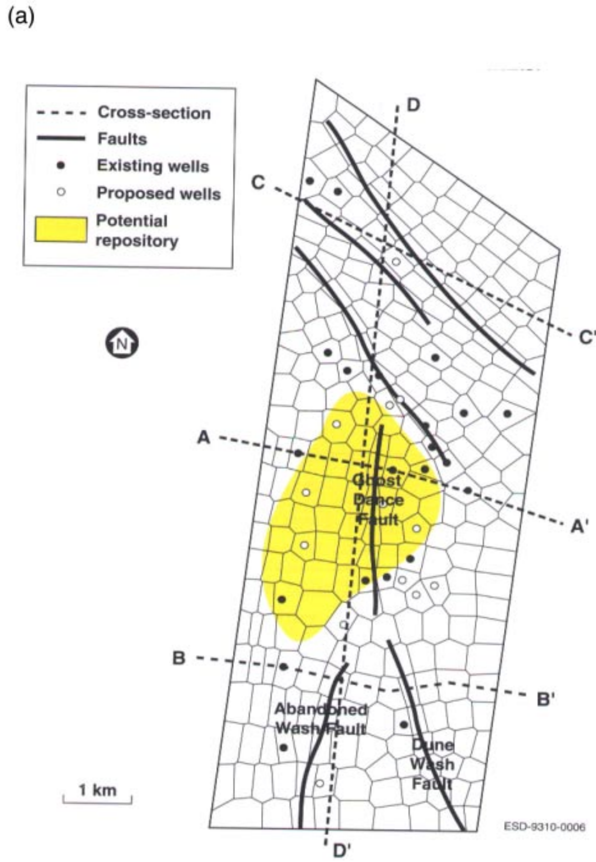


(a) 1-D model of ambient saturation conditions for different percolation flux values (UZ Flow - 1986)

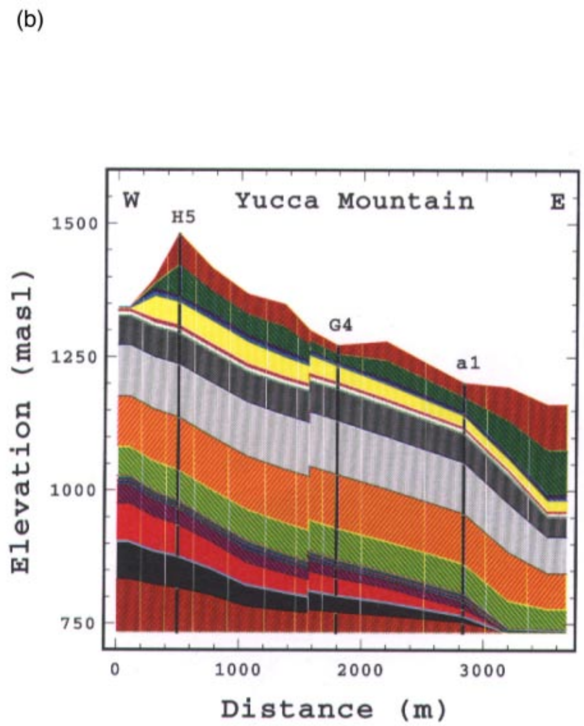
(b) 6 1-D columns in 1 transect with 1 mm/yr infiltration, composite-porosity and weep models (TSPA - 1991)

(c) 8 1-D columns from different areas, 0-5 mm/yr infiltration during dry periods and 10 mm/yr during wet periods (TSPA - 1993)

Figure 2.4-1.



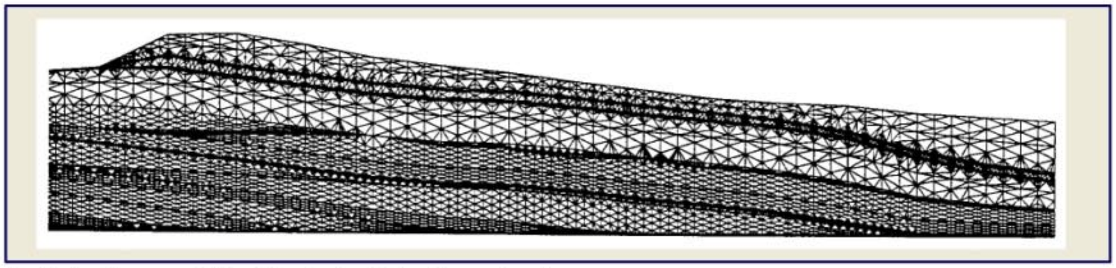
(a)
Cross-section
Faults
Existing wells
Proposed wells
Potential repository
N
D
C
C'
A
A'
B
B'
D'
Ghost Dance Fault
Abandoned Wash Fault
Dune Wash Fault
1 km
ESD-9310-0006



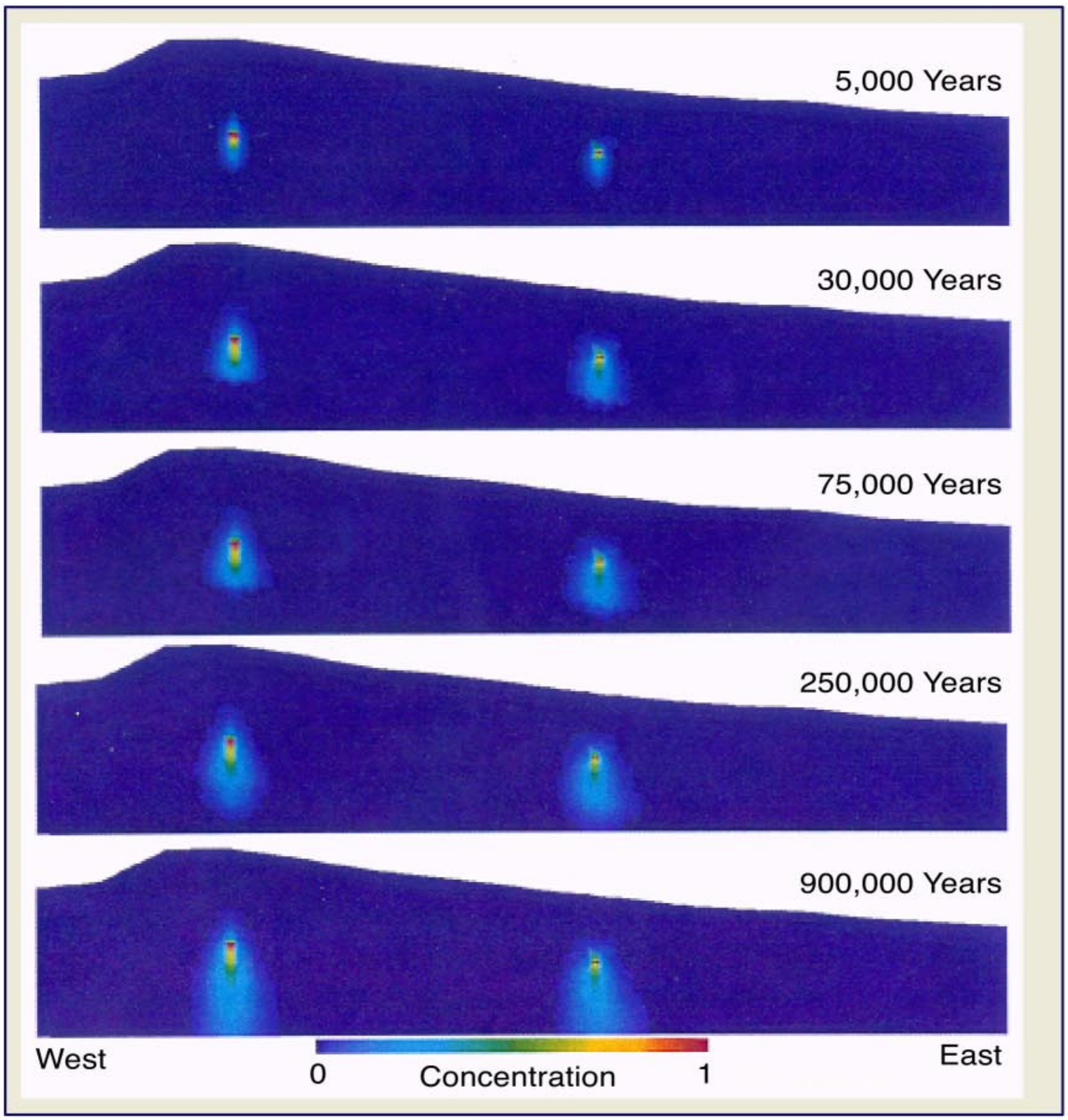
(b)
W
Yucca Mountain
E
H5
G4
a1
1500
1250
1000
750
Elevation (masl)
0
1000
2000
3000
Distance (m)

Figure 2.4-2.

UZ Transport - 1995 Model



(a) Finite Element Grid of the Antler Ridge Cross Section



(b) Simulations of Transport of ^{237}Np from the Potential Repository

Figure 2.4-3.

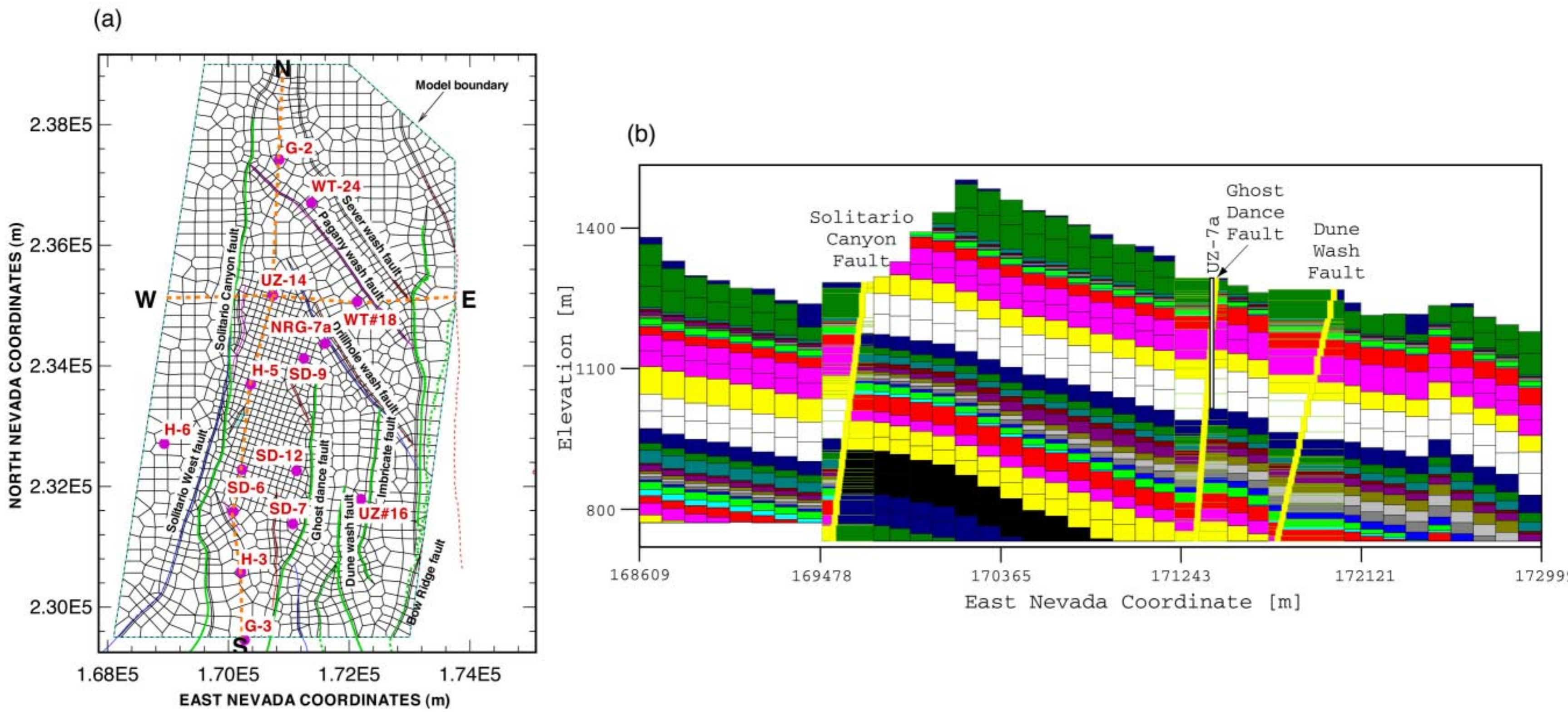

(a)
Model boundary
N
S
W
E
G-2
WT-24
UZ-14
WT#18
NRG-7a
H-5
SD-9
H-6
SD-12
SD-6
SD-7
UZ#16
H-3
G-3
Solitario Canyon fault
Solitario West fault
Sever wash fault
Pagany wash fault
Drillhole wash fault
Ghost dance fault
Dune wash fault
Imbricate fault
Bow Ridge fault
NORTH NEVADA COORDINATES (m)
EAST NEVADA COORDINATES (m)
2.38E5
2.36E5
2.34E5
2.32E5
2.30E5
1.68E5
1.70E5
1.72E5
1.74E5
(b)
Solitario Canyon Fault
Ghost Dance Fault
Dune Wash Fault
UZ-7a
Elevation [m]
1400
1100
800
168609
169478
170365
171243
172121
172999
East Nevada Coordinate [m]

Figure 2.4-4